Impact of Statistical Variability and Charge Trapping on 14 nm SOI FinFET SRAM Cell Stability

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Outline

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- ❑ 14 nm node DG SOI FinFETs
- ❑ Simulation of Random Charge Trapping and Statistical Variability Sources
- ❑ Compact Modelling Methodology
- ❑ Charge Trapping Impact on SRAM SNM
- ❑ Charge Trapping Impact on SRAM WNM
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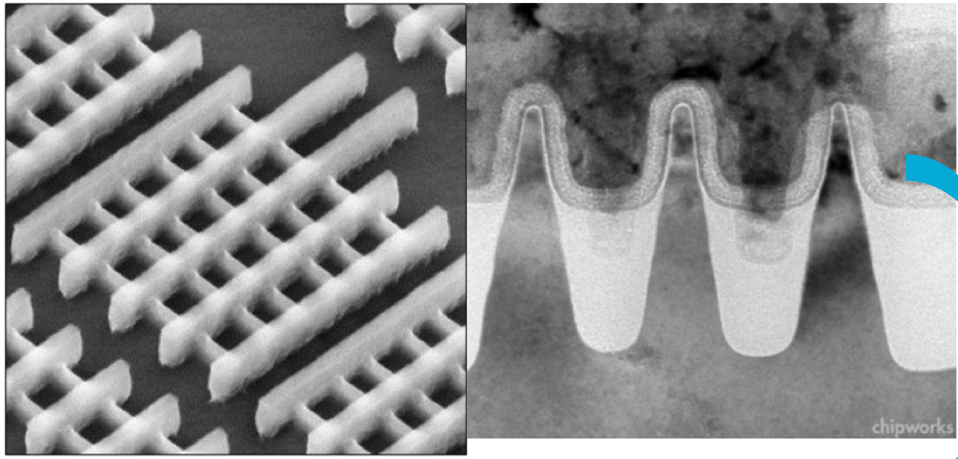
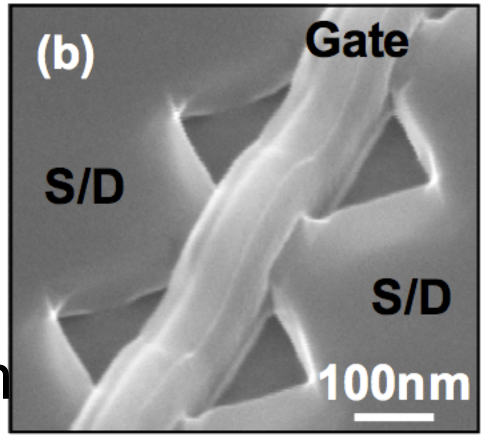
Introduction

- Why this study?
- Novel 3-D architecture FinFET will be widely adopted at 14 nm technology, with reduced variability on SOI substrate due to tolerance to low channel doping.
- However, (1) statistical aspect of reliability due to random individual trapping becomes an increasingly important issue. (2) In addition, charge trapping impact is affected by statistical variability sources.
- Accurately modeling reliability of nanoscale transistors in circuit level should take care of above mentioned properties, therefore requires a "statistical" method, rather than describing average reliability behavior.
- SRAM stability is susceptible to variability, therefore statistical study is needed.

FinFET

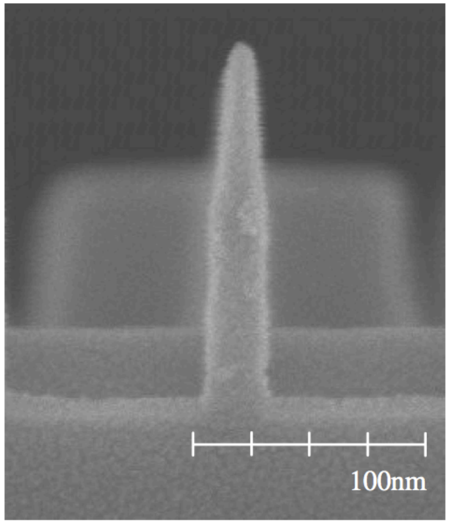


Intel
22nm

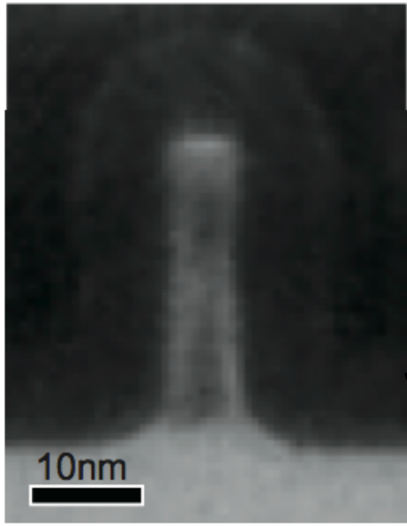


IMEC
Veloso et.
IEDM,
2009

Fin Edge Roughness:
width, height, slope



TSMC
Chang et.,
IEDM,
2009

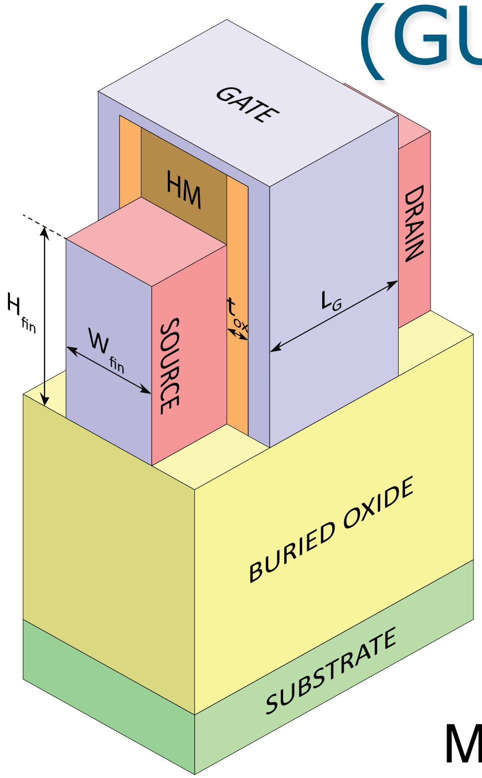


IBM
Chang et.,
VLSI tech.,
2011

Bulk substrate

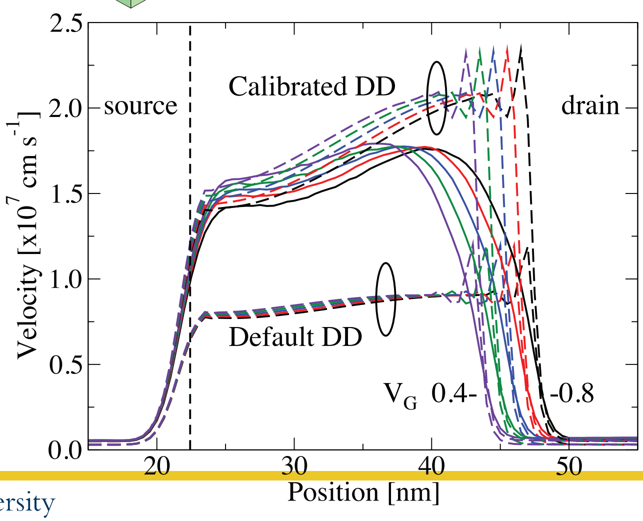
SOI substrate

Simulation Design of 14nm SOI FinFETs (GU-IBM collaboration)



Double-Gate SOI FinFET

Monte Carlo

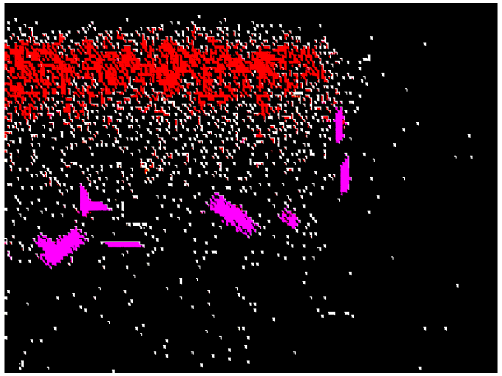


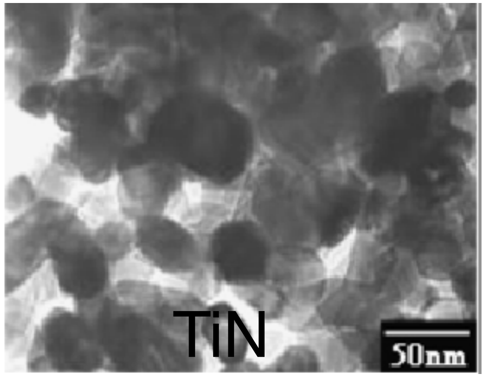
MC calibrated @ 85°C

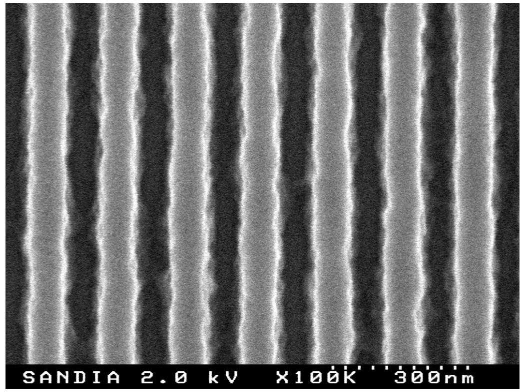
Lg (nm)	20
EOT (nm)	0.8
W_F (nm)	10
H_F (nm)	25
N_{SD} (cm^{-3})	3.0E20
N_{CH} (cm^{-3})	1.0E15
V_{DD} (V)	0.9
I_{OFF} (nA/µm)	10
I_{DSAT} (mA/µm)	0.9/0.8
DIBL (mV/V)	56/65

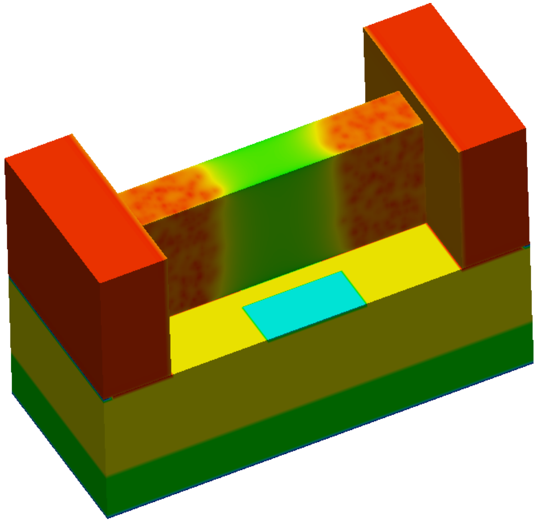
Ref.: ITRS 2010 update

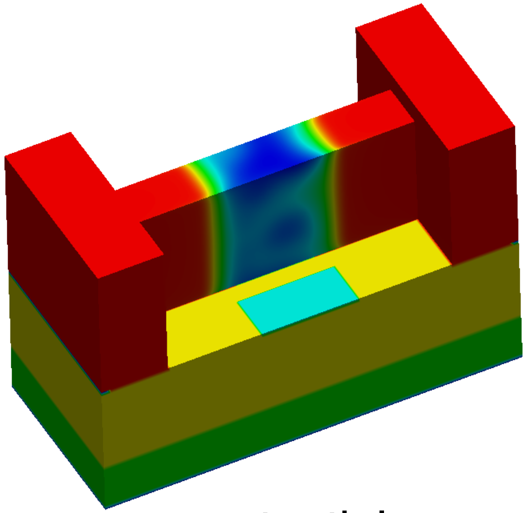
Intrinsic Parameter Fluctuations
Statistical Variability Sources

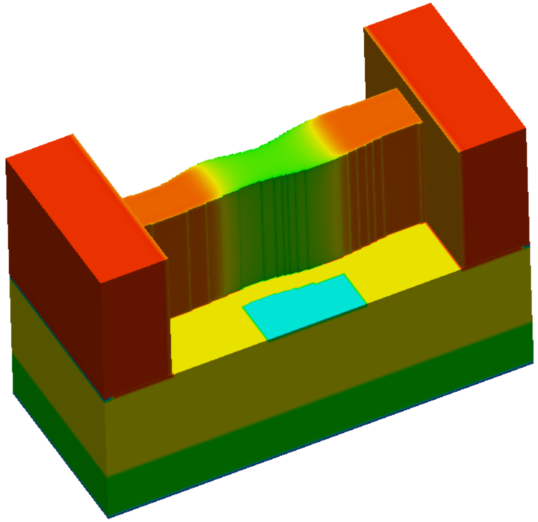












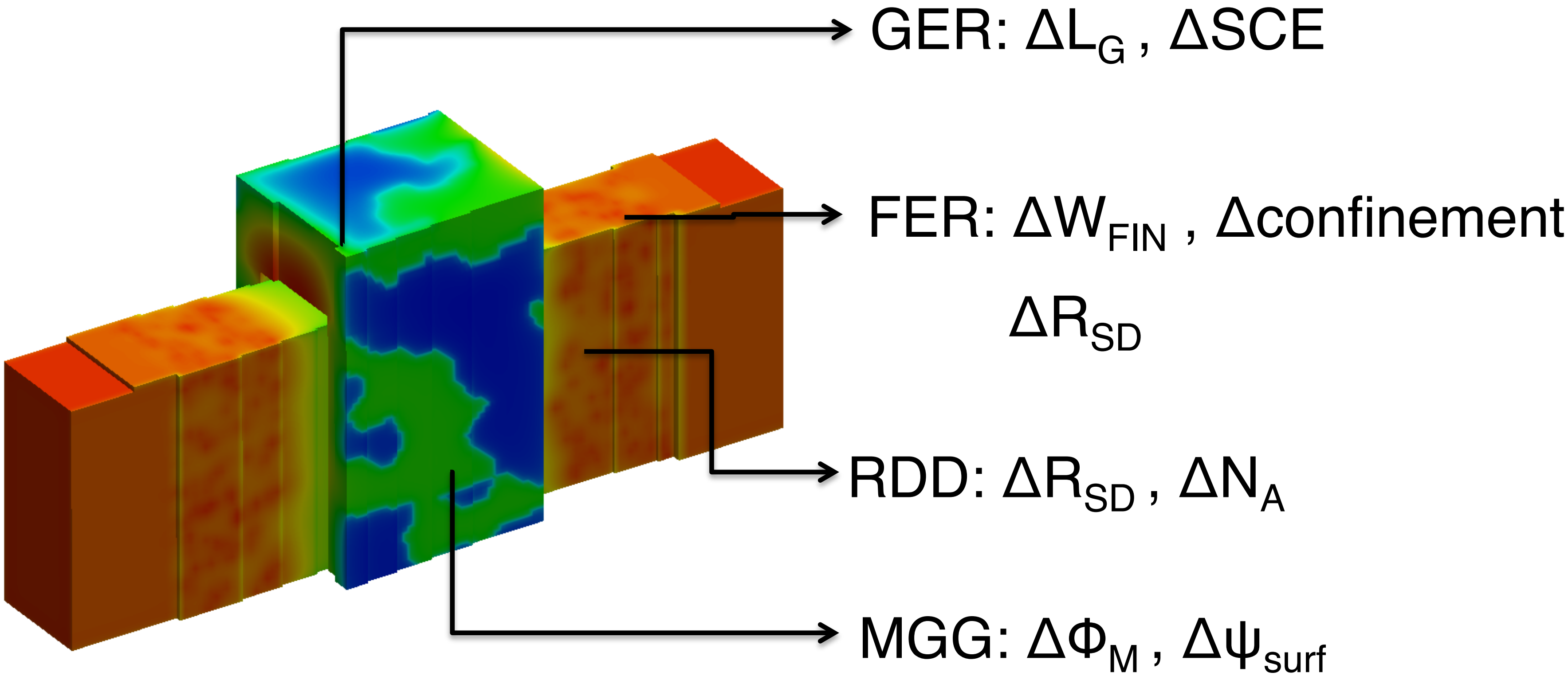
potential

Random dopants

Polysilicon/Metal Gate Granularity

Line Edge Roughness

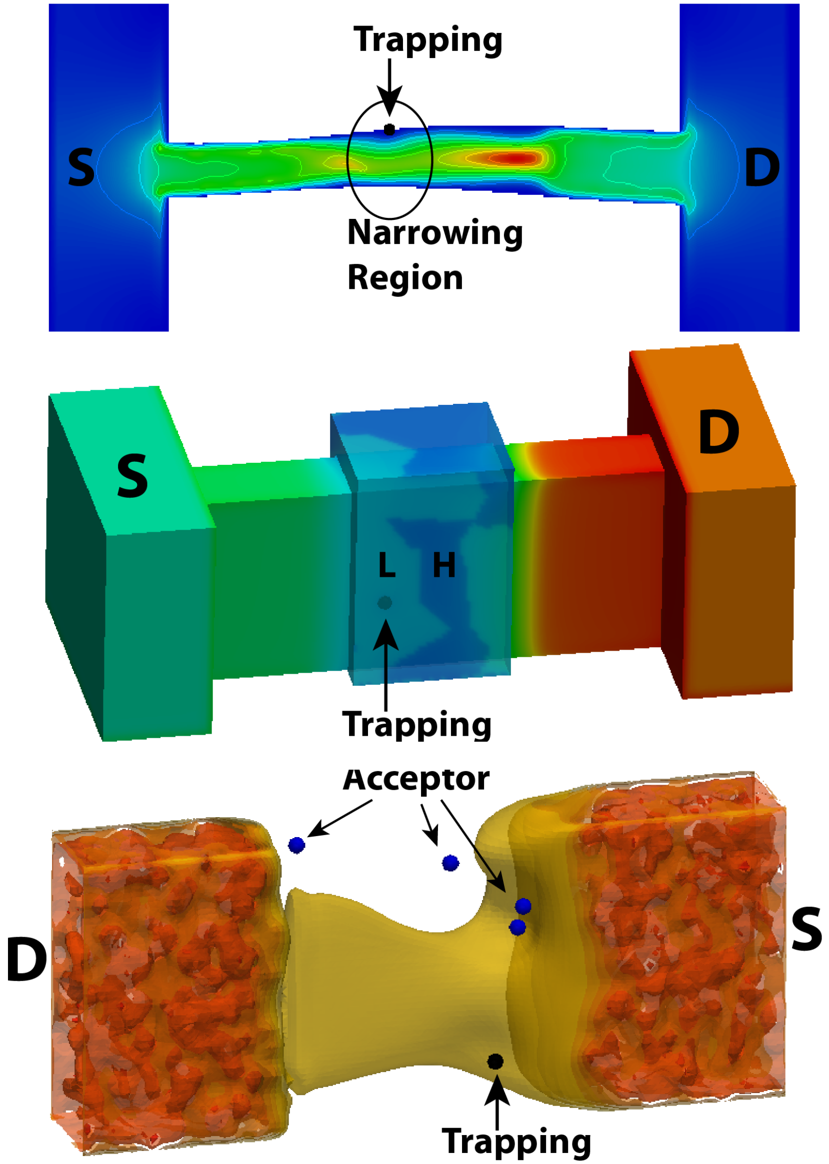
Statistical variability simulation



- Each variability source has different impact on the device parameters and performance.

Wang, et al, IEDM 2011, pp103-106

Interaction: Charge trapping vs Statistical variability sources

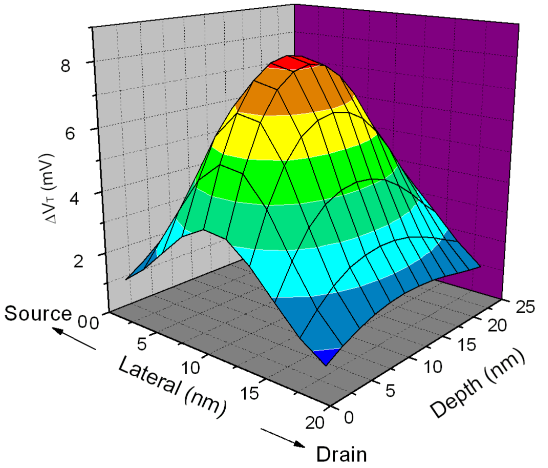


Sensitive regions

- FER: local shortenings
- MGG: metal grains with high currents underneath
- RDD: current percolation paths

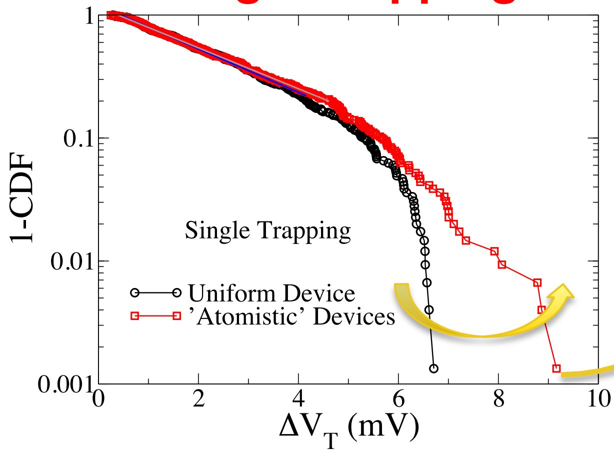
Wang et al, SISPAD 2012, pp.296-299

Vt RTS Distribution and Reliability are affected by Statistical Variability

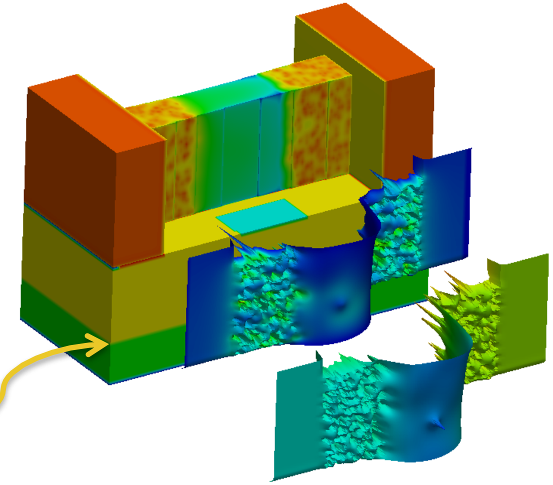


Uniform device

Single Trapping



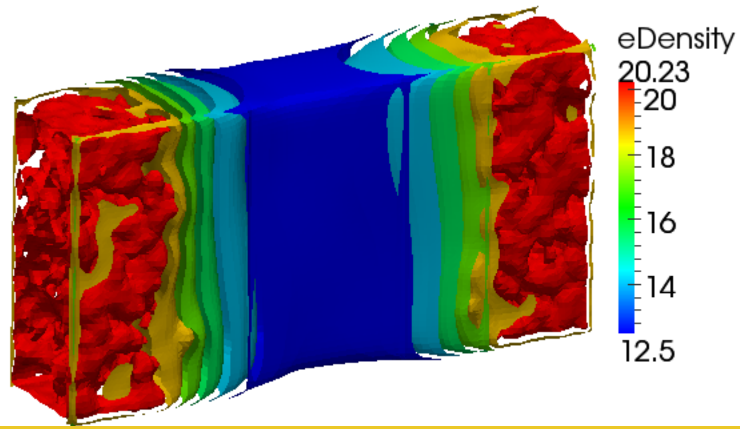
Wang et al., SNW 2012, pp.77-78

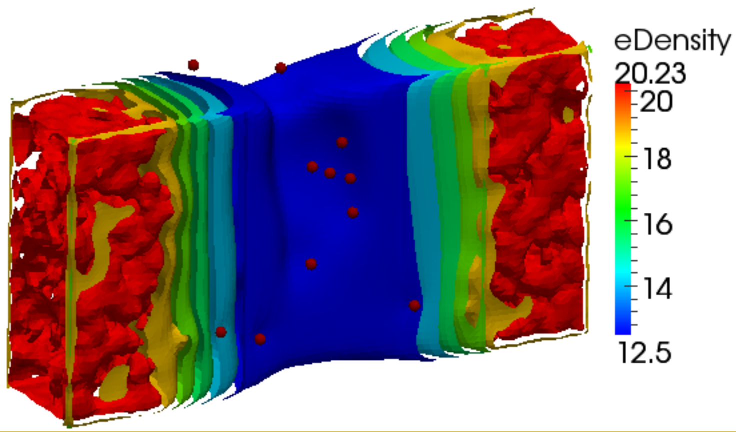


Atomistic device

- In the presence of SV, the RTS distribution tail is increased

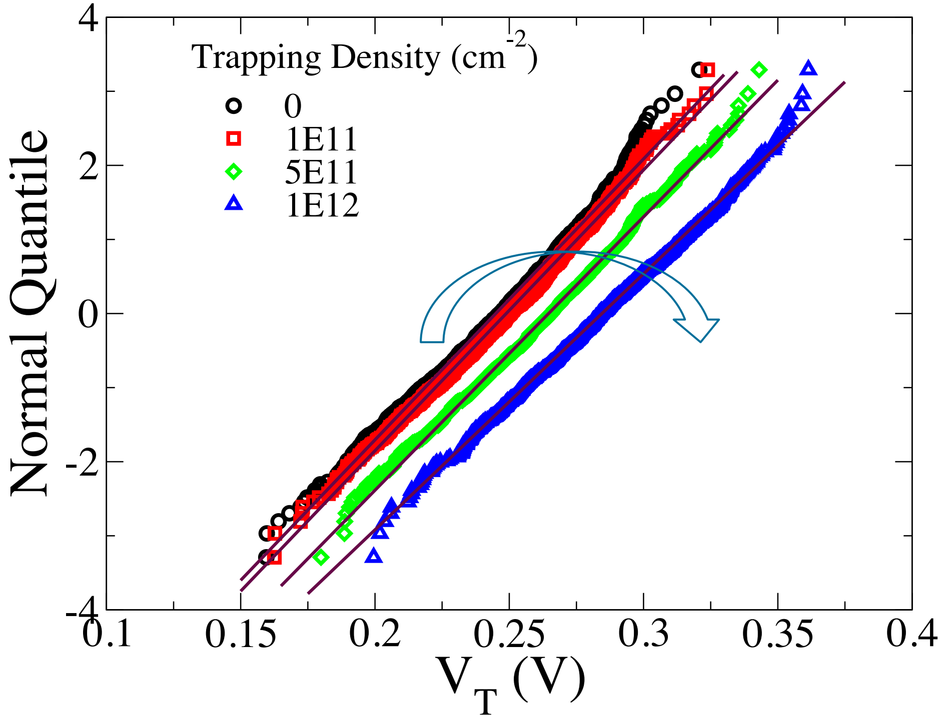
Multi-trapping





RTS: random telegraph signal

Random charge trapping effect on V_T

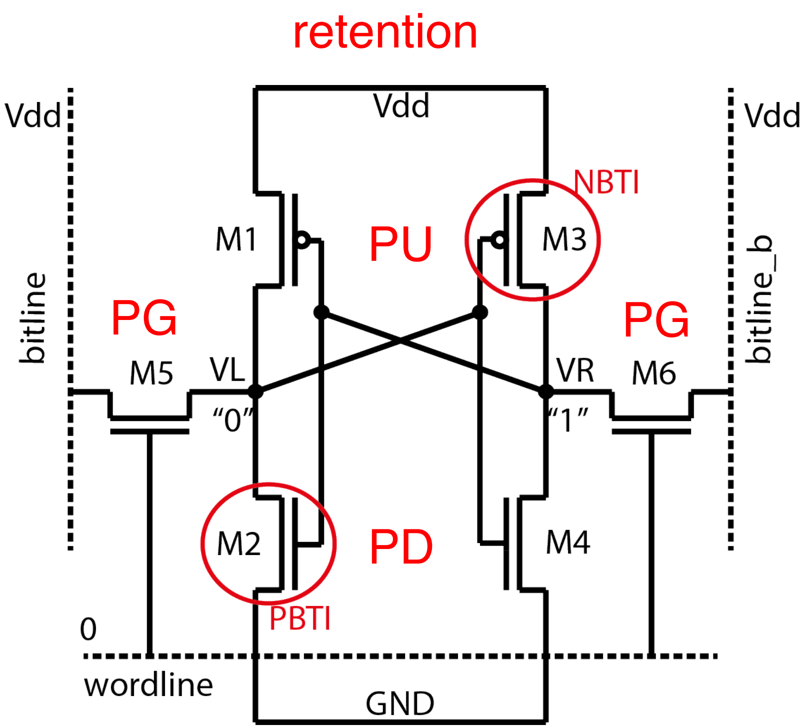


Poisson distribution of trapping charge number is assumed

- First, the average V_T shift increases with degradation heuristically;
- Most important, the statistical variability increases with degradation.

Statistical Compact Modelling Method

- A small set of BSIM-CMG compact model parameters is used to extract statistical samples at fresh stage, also applied to degradation.
- In circuits random fresh samples are assigned, responding stressed samples are put for stressed transistors.
- Assume trapping effect is dynamically recoverable.
- e.g., M2 is biased with high VG and low VD, subject to PBTI



6-Transistor SRAM cell

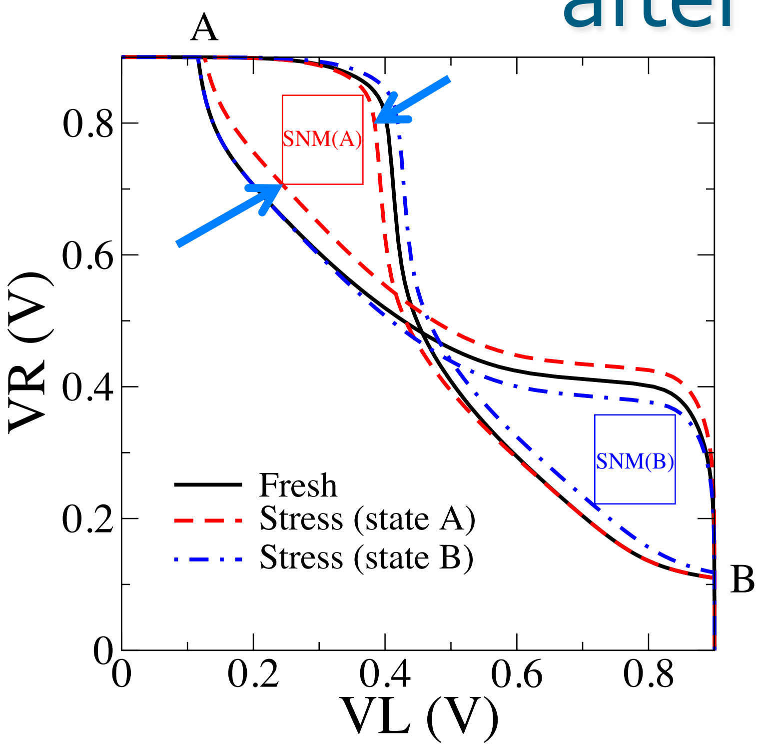
PU: pull-up transistor, p-FinFET;

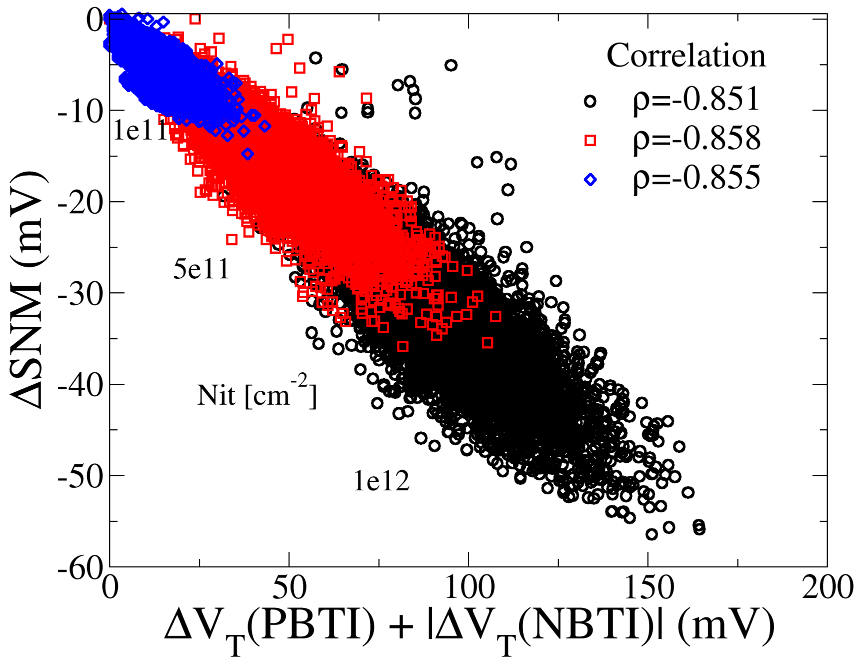
PG: pass-gate transistor, n-FinFET;

PD: pull-down transistor, n-FinFET;

University of Glasgow

What happens to SRAM SNM after stress?



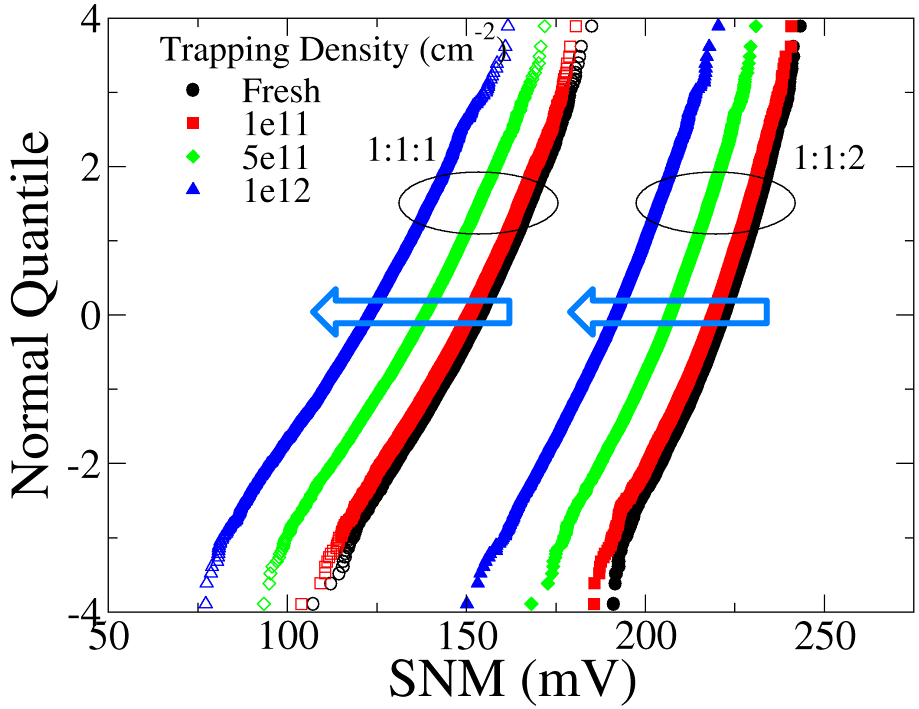


SNM: static noise margin, the SRAM stability for read mode

State A: left 0, right 1; State B: left 1, right 0

- Generally, stress induced trapping leads to less static noise margin
- Heavier N/PBTI, more threshold shift, less stability

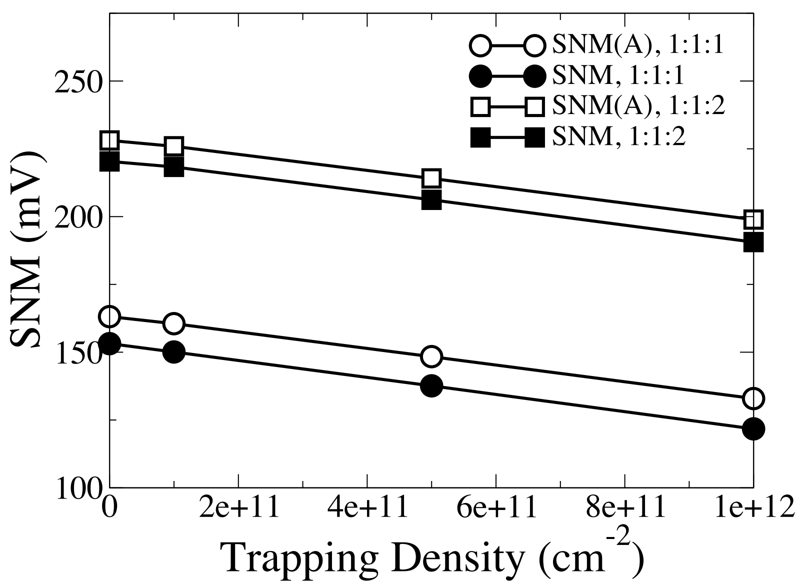
SNM Distribution

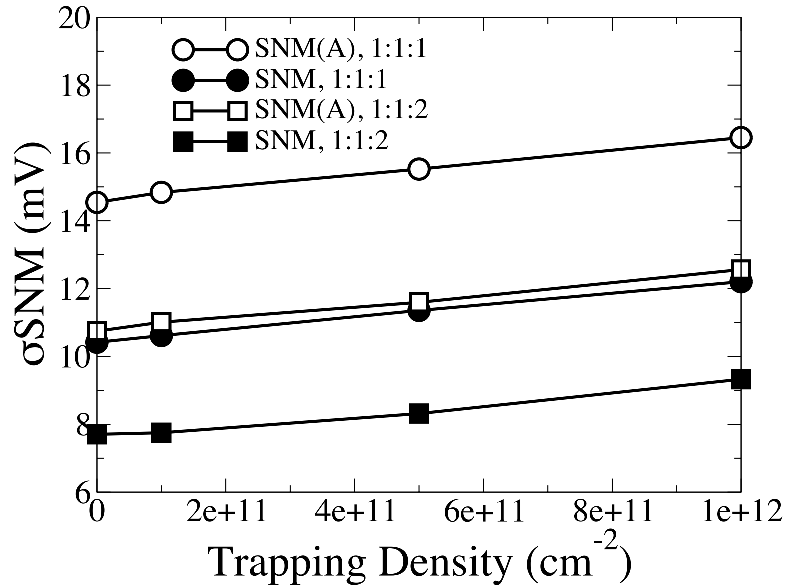


Two types of SRAM cells with fin-number ratio of PU:PG:PD, 111 SRAM and 112 SRAM are examined

- First of all, the distribution is non-Gaussian.
- Compared with 111-fin SRAM cells, 112-fin cells increase SNM.
- With charge trapping induced degradations, the SNM is reduced.

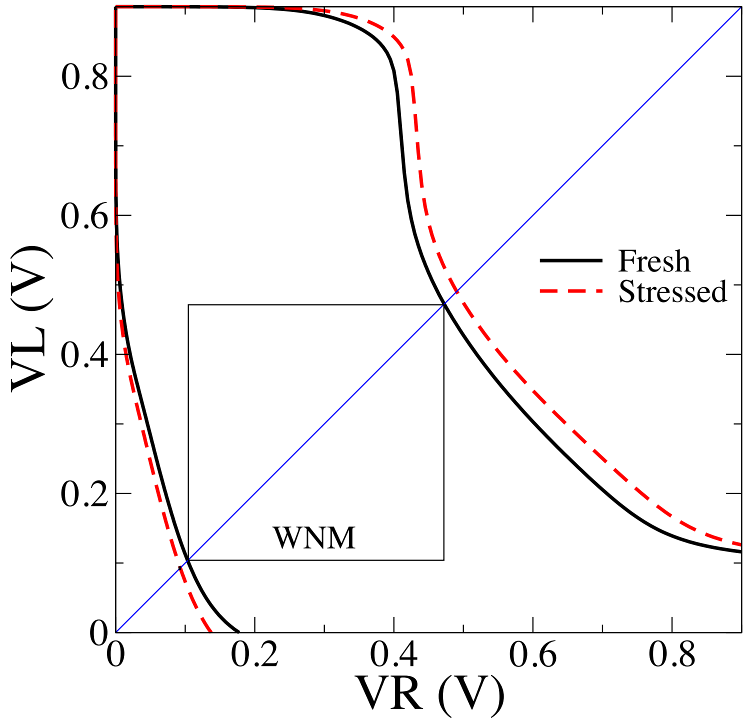
Charge trapping effects on SNM

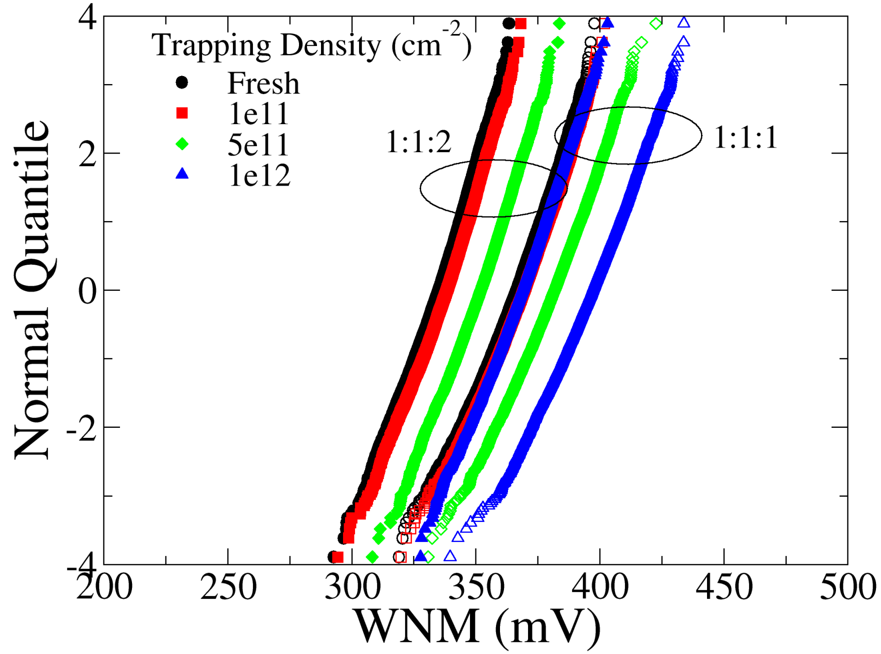




- The average SNM is reduced by up to 30 mV, with charge trapping induced degradations.
- The statistical variation of SNM increases by 30-40% with degradation.
- 112-fin SRAM cells show better stability. Compared with 111-fin cells, 112-fin cells increases SNM by ~45% in average.

What happens to SRAM WNM after stress?





WNM: write noise margin, SRAM stability for write mode

- In contrary to SNM, WNM increases a bit due to charge trapping.
- The WNM distribution is non-Gaussian.

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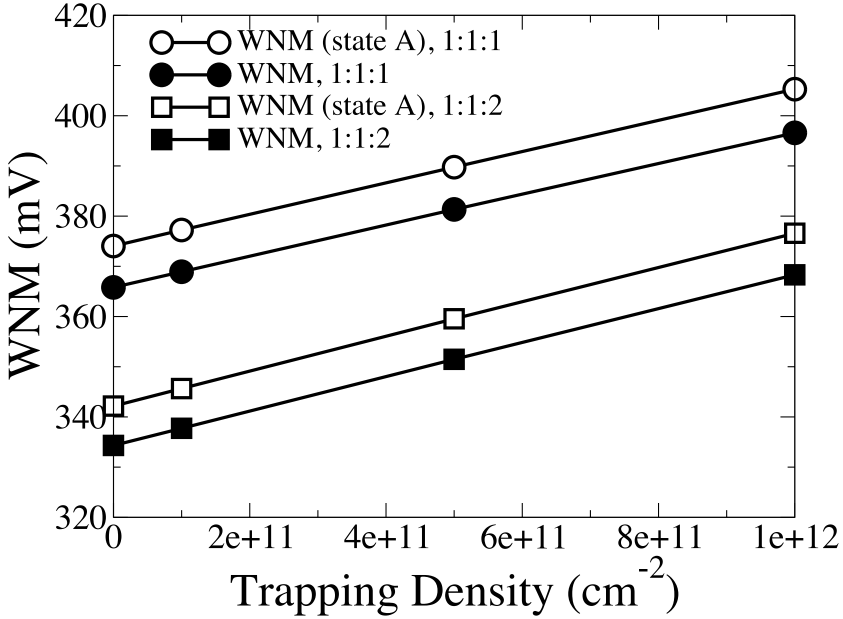
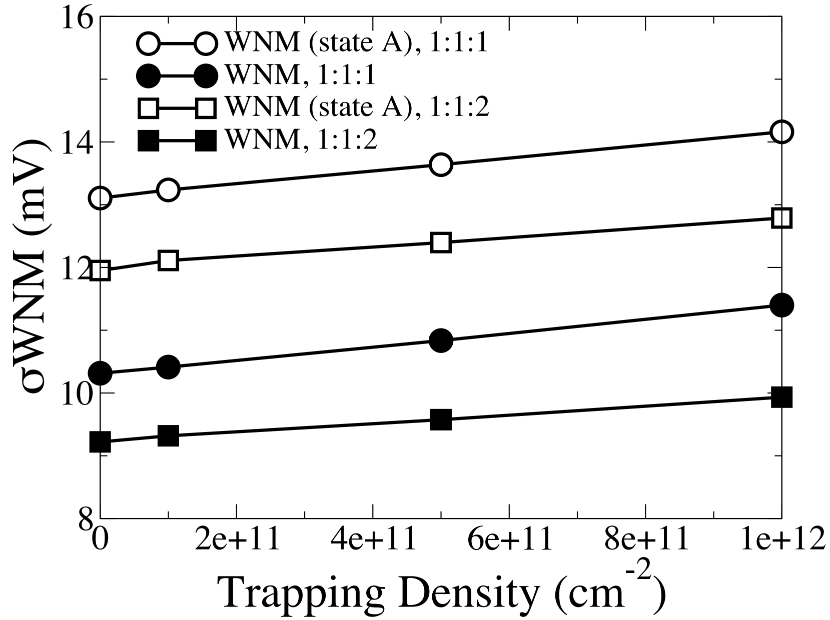
GSS

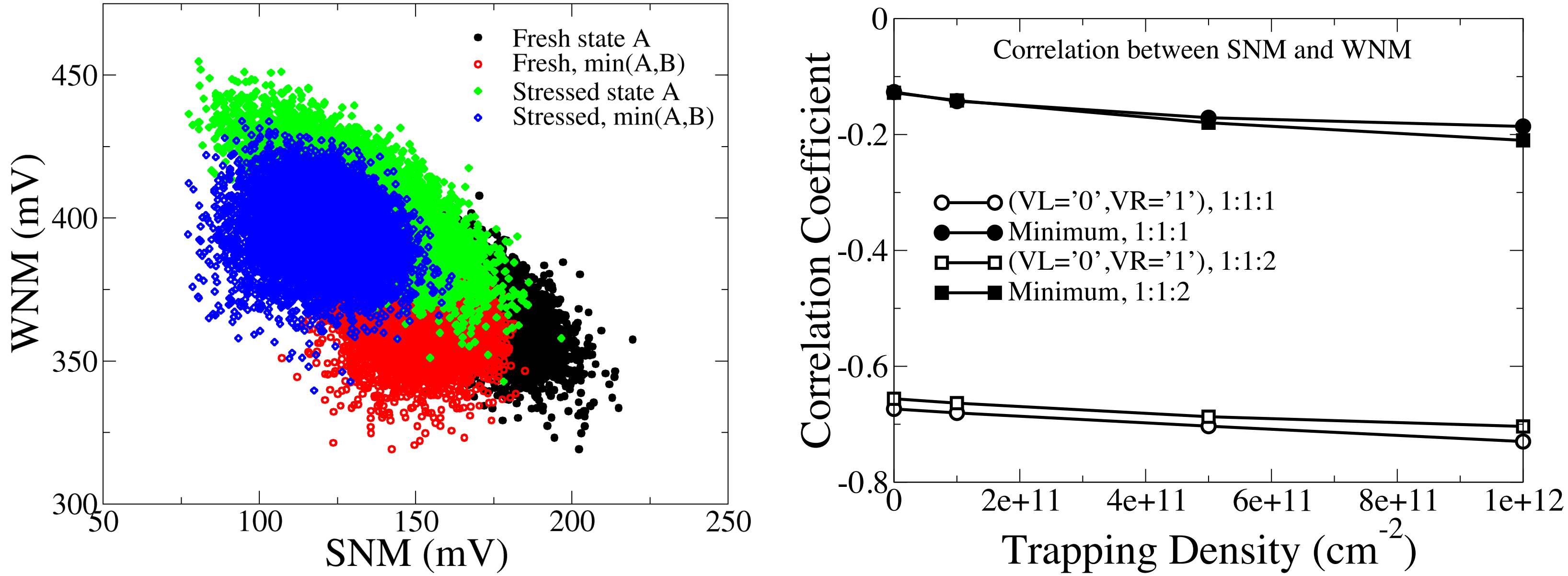
Charge trapping effects on WNM





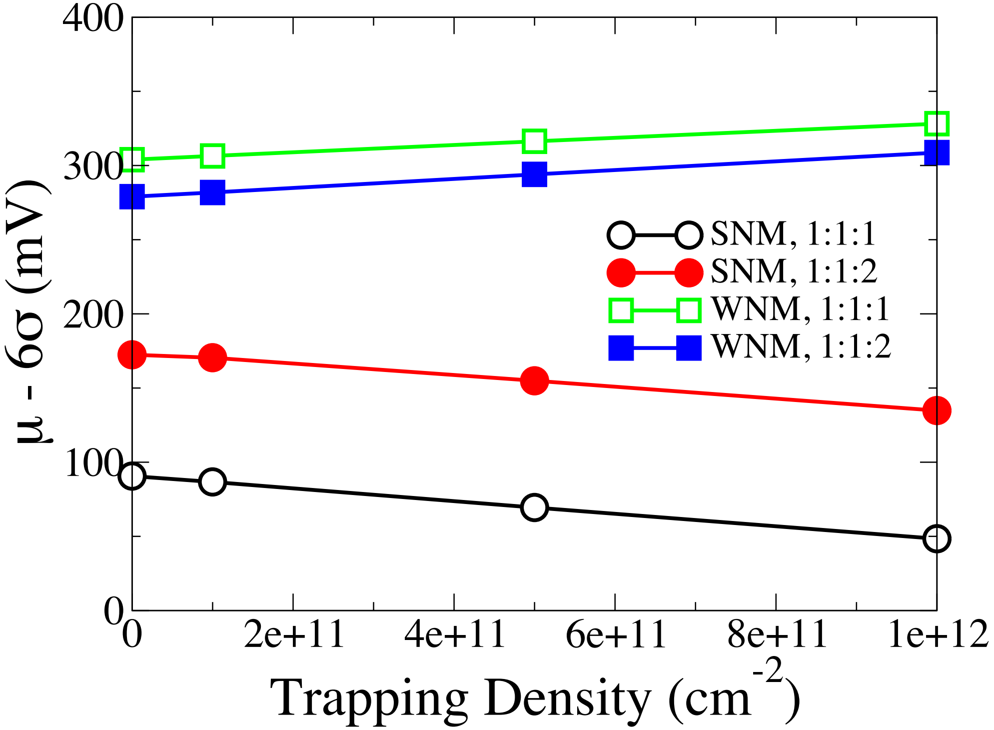
- The average WNM increases after stress, which is contrary to read SNM.
- The standard deviation of WNM increases after stress, which is similar to read SNM.

SNM vs WNM with SV and random charge trapping



- Anti-correlation between SNM and WNM exists for one storing node.
- Minimum defined SNM and WNM show decorrelations, due to statistically independent transistors responding to two storing states.

Impact on Six-sigma yield stress induced degradations



- 6-sigma of read SNM is greatly affected by stress induced charge trapping, not only due to average SNM reduction, but also by boosted statistical variability.
- 112-fin SRAM cells show much better stability than high-density fin cells.

Summary

- The random charge trapping effect can be accurately captured using the similar statistical compact modelling practice with statistical variability.
- SRAM cell read stability is degraded by stress induced charge trapping; The statistical variation of SNM and WNM increased with degradations.
- 112 FinFET SRAM shows much better stability compared with high-density SRAM cells.
- With the more random trapping, the read SNM six-sigma yield is reduced dramatically due to enhanced variation.

Acknowledge

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Thank you for your attention.